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ECL 122

TERRY ABBEY

Pumping Waste Acid Deep Underground

"Our hunch is that the deep well over at Great Northern Steel collapsed from hydrostatic pressure in the annulus when the flow was shut off. We think our design will prevent that, but we want to be as sure as we can. We also want to be sure that we will spot any irregularities in operation early." Bob Martin, superintendent of Support Facilities Engineering at the Northern Indiana plant of Central Steel Corporation was referring to a new 4,300 foot well being drilled for disposal of "waste pickle liquor", a mixture of primarily hydrochloric and sulphuric acid which has been used to take chemical scales off steel ingots before they are rolled into ingot. This acid, (specific gravity ranging from 1.1 to 1.2) which was at present being pumped into a nearby river, would pass down a 2-7/8 inch diameter fiberglas reinforced plastic pipe to displace saltwater in a sandstone layer running from 2,200 feet deep down to 4,300 feet which was presently permeated with saltwater.

Prepared in the Design Division, Mechanical Engineering Department, Stanford University, by Karl H. Vesper with support from the National Science Foundation.

Terry Abbey, who had been with Central two years since graduating in Civil Engineering from a prominent Michigan university, had taken over as engineer in charge of the waste acid disposal project around November of 1966. It was now February of 1967 and detail design of filtering and pumping facilities was in progress. Drilling was scheduled to start in May. One part of the design not yet fully decided was what instrumentation should be provided on the well. Terry thought he should review this question, particularly as regarded possibilities of leakage or collapse of the line. It was expected that the well of Terry's company, Central Steel, would in principle be similar to that of the well already sunk by Great Northern, which had recently collapsed twice, except that precautions against such a failure would be taken. A current discussion of the waste disposal problem which appeared in Business Week Magazine is reprinted in Exhibit 1.

Existing Well at Great Northern

Great Northern first considered such a well in 1959, received approval for drilling from the State of Indiana in August 1964, started drilling on September 14, 1964, and "bottomed out" on October 4, 1964. As shown in Exhibit 2, the well provided essentially two concentric tubes, an inner pipe of two to three inch diameter called the "injection tube" through which acid was pumped down, and an outer annulus ("casing") through which water was pumped. The water outside the plastic pipe served to counterbalance the pressure of the acid standing inside, thereby supporting the reinforced plastic injection tube against bursting and also providing a barrier to the acid against corroding the outer casing, if the plastic pipe failed. At the bottom the annulus was partially sealed by a "packer" which had holes in it to allow a trickle of water (about one gallon per minute) to flow through. This trickle of water served to keep acid away from the bottom of the well and prevent upward migration of the acid.

The well casing, after passing down through several horizontal layers of shale which served to isolate the acid permanently from the surface, ended in a porous "Mt. Simon sandstone" deposit presently saturated with

with salt brine (three times as saline as seawater) at a temperature of 80°F. The natural pressure was such as to force this brine up through any hole drilled in the shale to within 400 feet of the surface. Consequently, the acid had to be pumped to force this brine back through the sandstone at the desired flowrate. First, however, 35 million gallons of fresh water were pumped into the sandstone so the acid could not mix with the saltwater and form precipitates which might plug the sandstone, (12% porosity). The acid was to pass through a 0.6 micron filter before entering the well so no particles could plug the sandstone. Total costs of the well plus ancillary filtering and pumping facilities were estimated at around $2 million for installation and the first seven years' operation. Disposal of acid through the Great Northern well began April 3, 1965.

There shortly followed two failures during temporary shutdowns of the Great Northern pumping station. Both times the inner reinforced plastic pipe (injection tube) carrying acid collapsed inward at a depth of 550 feet. To cure the problem, Great Northern installed a section of 2 inch diameter pipe in place of the original 3 inch diameter for 400 feet above and 400 feet below the 550 mark to provide greater strength against crushing. By early 1967 there had been no additional failures. A cost comparison estimated for the well system as against the alternative of chemical neutralization of the acid appears in Exhibit 3.

Central Steel's Design

The proposed new well for Central, being one hundred yards inside of the Central Steel property line and only a few miles from Great Northern's well, was expected to have essentially the same geological environment. Its capacity was initially to be 120 gallons of acid per day at 150°F., possibly increasing ultimately to 300 gallons as steel production was expanded. Provision would be made to store 100,000 gallons of acid in each of two tanks near the well and to pump river water (heated to a minimum of 50°F. in the winter to prevent precipitation) in place of acid, in case the flow of acid from the plant should stop. Central engaged a well consultant and the same drilling company which had worked on Great Northern's well.

Several alternatives had been suggested as ways to preclude such collapse as had occurred at Great Northern. One was to use 2-7/8 inch tubing and in other respects, make the Central well like Great Northern's final design (cross-sectional dimensions appear in Exhibit 4). This approach was favored by the driller. However, the consulting geologist recommended that Central's well not use a "packer" at the bottom between the inner and outer casings. He pointed out that by eliminating the packer, water would not be restricted in flowing down the annulus, so that pressures of water and acid would remain equal at the bottom of the injection tube. The packer at Great Northern, he said, had probably held the water column back during shutdown as the acid level dropped, thereby imposing a high differential hydrostatic head in the annulus which crushed the inner pipe. Furthermore, the packer was difficult to install, particularly to allow for slip of the inner pipe needed for differential expansion due to temperature changes in the flowing fluids. (The coefficient of linear expansion for the plastic pipe was 9.5×10^{-6} in/in/°F.) On the other hand, the driller pointed out that the packer might help prevent acid from migrating back up the annulus, and it would serve to hold the injection tube from falling in case of a break.

Another alternative considered was to plug the annulus at the bottom and fill it solid with plastic. "The plastic might cost $10. to $15. a gallon," Terry observed. "I don't know whether there would be problems with thermal expansion, but if so the plastic might crack and let the acid eat through the steel. Then it could flow out into some fresh water zone without our even finding out until it was too late. Also, we wouldn't be able to change capacity without drilling out all the plastic. Ultimately we think we may want to put in a 4-1/2 inch diameter injection tube (center pipe for acid). We could maybe have used that size now, but management told us to stay pretty close to Great Northern's design, so we chose not to go to a larger diameter."

The final decision was that Central would use a 2-7/8 inch pipe all the way. Whereas Great Northern had used centrifugal pumps on both annulus and injection tube, however, Central would use a positive displacement pump on the annulus and centrifugal on the injection tube.

Terry Abbey

Terry also did some checking to see if stronger pipe were available, but did not find any. He wrote the Poxy Pipe Company, from which the injection tube material was bought, to obtain figures for allowable stress on the pipe and received the figures shown in Exhibit 5. Shown in Exhibit 6 are pressures required to force varying flowrates of acid into the sandstone formation and head loss due to friction of the pipe for various flowrates. Terry obtained these figures from the consultant.

"Deciding what information you need and collecting it is 90% of a job like this," Terry observed. "In school you may get the impression that engineering work involves lots of formulas and calculations, but here that turns out to be just a small part. You're on the phone, you're writing letters and specifications, reviewing catalog data and buying things through the purchasing department."

The idea for this project had initially been suggested in a brief memo called an "engineering request" which had come from an assistant to one of the vice-presidents. A "project scope" was then prepared, outlining the proposed design, and estimating the work schedule and costs. Approval of an engineering committee and of the Board of Directors was then obtained, as was required on all engineering projects, after which preparation of detailed specifications, solicitation of contractor bids and execution of the project ensued. Practically all new equipment for the plant was purchased through specifications, and it was the project engineer's responsibility to assure that they were appropriate, complete and complied with by suppliers.

One of the senior engineering managers at Central Steel observed that the engineering work done by steel companies does not normally include the design of steelmaking machinery. "We get ideas for machinery improvement or for new equipment that we need and pass these along to companies like Bliss and Blaw-Knox, and they do the engineering and manufacture the machines. Our engineers write the specifications by which we then buy the equipment. This involves a lot of technical variety, and it's why

we look for problem solving ability first when we hire engineers, not for specialized degrees. Sometimes a superintendent of the plant will call for a crane when the job could be done with a jack. Our engineer has to have the horse sense to recognize something like this and also enough diplomacy to make the superintendent feel good about being set straight."

Projects with which Terry had worked since joining Central had included among others, such things as selection of a sump pump for a degreaser pit, selecting and ordering an automatic sampling device for sewer outfalls, and preparation of purchase and installation specifications for a pump and related controls to remove waste from a coke plant. He had entered the acid disposal project at the stage of preparing specifications for the system and within three months had been made engineer in charge of the project. "Every day you learn something new in a job like this," Terry commented, "especially from vendors. I learn specifics about instrumentation from them a lot faster than from catalogs. The basic understanding, of course, you have to get from school or textbooks so you know what you're looking for and what questions to ask."

Precautions

"One question I think I should check on here is what pressures act on the injection tube for different flowrates and acid densities," he continued, "and the calculations shouldn't be too hard to make. What, for instance, is the worst situation that could arise? And can the Great Northern failures really be explained on the basis of hydrostatic pressure, or was it something else like 'waterhammer', as some others believe? Bob Martin has been asking what might happen if gas bubbles go down the acid line and float back up the annulus, which he thinks is also a real possibility.

"Then there is the question of what safety valves and alarms we should specify for the system. To order instruments and controls we'll have to know scale ranges of the things like pressure and flows we want to measure and regulate. Hopefully, nothing will go wrong. But if it does, we'd better catch it before it leads to more trouble."

Exhibit 1 - Excerpt from Business Week

Watery grave for Lake Michigan?

Pollution-control officials worry that Lake Michigan may soon become a ghost lake—chiefly as a result of industrial waste. But some companies are striving to reverse the tide

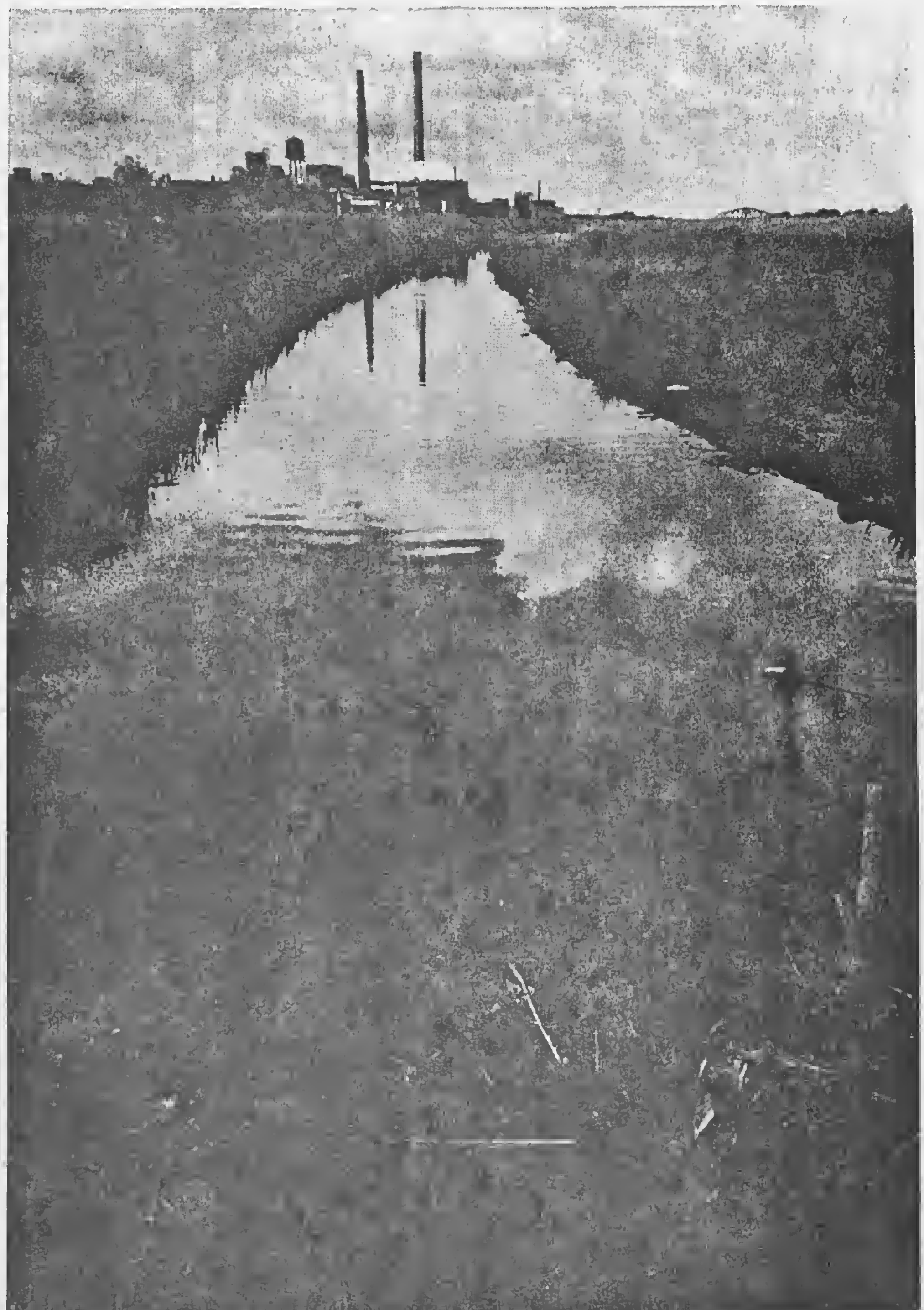
Lake Michigan means different things to different people. Bathers in four states love its 700 miles of shoreline, boaters love its great waves and oceanic distances, Chicagoans revere it as their source of drinking water.

But for everyone in the area, the 22,400-sq.-mi. body of water has a darker side—as a convenient receptacle for industrial waste and municipal sewage, it is becoming a colossus of pollution.

Pollution-control agencies fear that in 10 years, despite present abatement programs, Lake Michigan will become another Lake Erie—clogged with algae and murky with waste. The comparison is a chilling one, for if Lake Erie is not already dead, it is moribund. Commercial fishing has nearly disappeared, and at its dead core is a 2,600-sq.-mi. patch of water devoid of all oxygen in summer. "Grossly polluted, aesthetically displeasing, and even hazardous to health" is how George Harlow, director of the Federal Water Pollution Control Administration in Cleveland, describes the water around the major Erie ports.

The big offender. If Lake Michigan is not yet the same sort of ghost lake, it soon could be. Of prime concern to pollution-control authorities is the vast industrial complex— steel, oil-refining, and chemical companies particularly—along the lake's southern basin, which stretches about 25 miles from southeast Chicago through Gary, Ind. One official estimates that "70% of Lake Michigan's pollution is generated in this small area." Industry is trying to make amends. Some 20 companies operating along the Indiana portion of the basin will probably spend upwards of $100-million by 1970 to meet that state's stringent new control requirements.

Yet industry alone is not responsible. Representatives of the U.S. Army Corps of Engineers were summoned to an informal Congressional hearing by Rep. John C. Kluczynski (D-Ill.) early this month to explain why the engineers continue to dump



Tributary to Lake Michigan, the Grand Calumet River, is here heavy with sludge and algae, which are caused in part by industrial oil, acids, and ammonia.

contaminated dredgings from the Indiana Harbor Canal into Lake Michigan. (The engineers clean the canal every 18 months and the dredgings are prodigious: The canal is bordered by Inland Steel Co. and Youngstown Sheet & Tube Co.)

Switch. Corps officials replied that because the cost of landfill disposal methods was still prohibitive, dumping would continue through at least 1970. But some days later—in an apparent response to public pressure—the engineers announced they had agreed with Inland and Youngstown to deposit this year's remaining dredgings—120,000 cubic yards—in diked landfills at both companies.

Col. Edward A. Bennett, chief engineer for the Corps' Chicago district, concedes that critics have a legitimate case to make. But his rejoinder is of small consolation to fresh-water enthusiasts: "Since Indiana Harbor flows into the lake anyway, we're simply moving the dredgings from one point to another, within the system. We're really not adding to the problem."

Such answers are all too typical of the "Who, me?" attitude of many companies along the lake's southern basin—at least in years past. Or so says one official of the Federal Water Pollution Control Administration. The same official points out just why Lake Michigan's problems are so acute. "The recovery capabilities of a fresh water lake aren't nearly as good as those of, say, a river," he explains. "A river is constantly flushing out, but Lake Michigan just sits there, almost like a giant bathtub."

Dying lake. FWPCA, the water pollution control arm of the Dept. of the Interior, and Indiana and Illinois state agencies are working together, but they wonder aloud whether present regulations are not a case of too little and too late.

Until late 1964, regulation of water pollution in the area was flimsy at best. In December of that year, the federal government called three agencies—the Chicago Sanitary District, the Illinois Sanitary Water Board, and the Indiana Stream Pollution Control Board—to the conference table. At their meeting the following March, the conferees established a technical committee to develop water quality criteria for the southern end of Lake Michigan.

Option. Soon after the conference, Congress passed the Water Quality Act of 1965, giving states the option of developing sets of water standards and submitting them to the federal government for approval. Using criteria developed from the 1965 conference as a base, both Indiana and Illinois offered programs, complete with timetables for the installation of pollution abatement facilities. Indiana has been cleared and Illinois should be shortly.

The Indiana enforcement plan mentions companies by name. Among them are three steelmakers—Inland, Youngstown, and U. S. Steel Corp.—considered by government pollution control experts to be the biggest polluters of all. The companies expel large quantities of ammonia, cyanide, phenol, iron oxides, oils, and sulfuric acid into waterways flowing into Lake Michigan. Says a bitter Robert J. Bowden, chief of FWPCA's Calumet area surveillance project: "The chemical and oil industries themselves would cause serious pollution problems. But with the steel companies there, you hardly notice the others."

Reluctant. Inland, Youngstown, and U. S. Steel use close to 3-billion gallons of Lake Michigan's water each day. All three are reluctant to reveal the quantities of pollutants they discharge into the lake, but FWPCA cites what it considers a fairly typical example: 37,000 gallons of oil each day pour into tributaries of Lake Michigan.

Steelmakers in Indiana say they can put pollution-abatement facilities into operation on schedule. Inland will sink $17-million into its new program to meet the standards, Youngstown about $12-million. Currently, the three steelmakers have until June 30, 1970, to get started. Because of the volume and complexity of their effluent, they have 18 months more than other companies on the southern basin of the lake. But eagerness to get pollution control under way may wipe out this cushion. Insiders report that Indiana's Stream Pollution Control Board will meet with the steelmakers next week to discuss a Dec. 31, 1968, deadline, the same as Illinois'.

Later, please. The steel companies would prefer getting state and local agencies on a 1970 schedule. John Brough, director, Air and Water Control at Inland (companies avoid the word pollution in titles), explains why steelmakers have waited so long in stepping up their control efforts: "Since 1950, all our new facilities have included abatement. Before that, facilities were controlled to meet specific problems. Most of these were controls to pull out bulk materials." Says another steel official: "We've known the stuff we dump is deadly, but we've been doing the best we can. We don't see any evidence that other industries are working as hard."

The industry's defense of its abatement program is this: We'll do all we can, but we are accountable to our stockholders, and pollution control equipment doesn't put a cent in their pockets.

The effluent society. But the widening concern over pollution, even from stockholders, is making this defense untenable. U. S. Steel doesn't expect to stop pollution-control efforts and expenditures when it has met present deadlines, be they 1968 or 1970. Charles A. Bishop, director of U. S. Steel's abatement program, looks forward to more, and tougher, standards, and isn't griping about finding solutions.

U. S. Steel's South Works and Gary mills, hugging the Lake Michigan shoreline, already have made such improvements as separate sanitary sewage systems.

Indirect. It is true that the steelmaking process produces very little phosphate waste, a key ingredient of nutrients fostering algae growth. But it does produce ammonia, which contains nitrogen, another contributor to nutrients.

What authorities fear most is the increasing cost of treating water for drinking. FWPCA's Bowden points out that water treatment costs decrease as one moves farther away from the southern basin area. He noted that Hammond, Ind., which is in the heart of the area, pays about $36 per million gallons to have its water treated. The cost in Chicago's central district, however, is only half that. "If pollution continues at this pace," says Bowden, "water could become as expensive as your food bill. Would you take a shower in the morning if it cost you as much as your breakfast?" **End**

Exhibit 2 - Cross Section of Great Northern Disposal Well

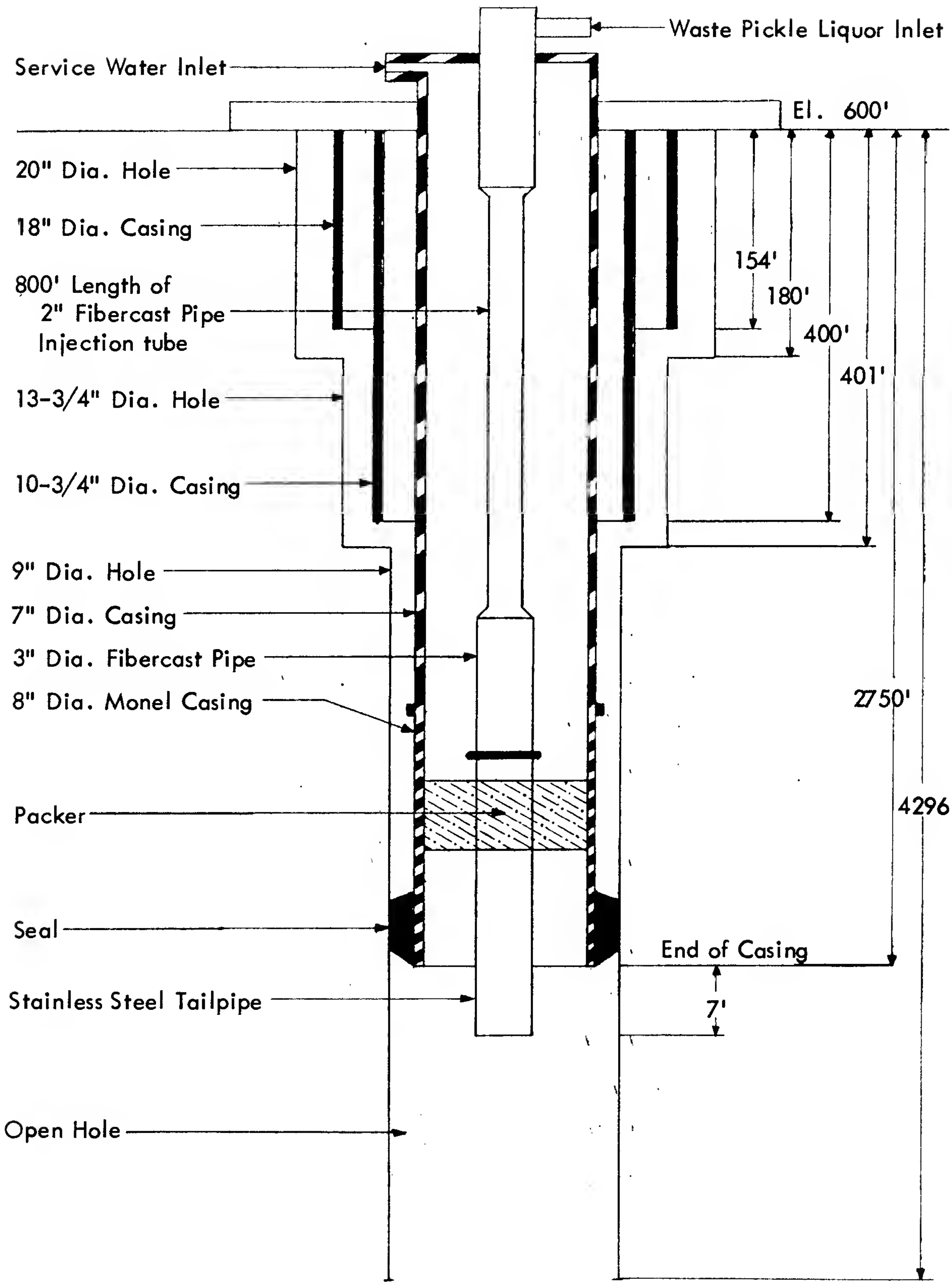


Exhibit 3

GREAT NORTHERN WASTE ACID DISPOSAL COST COMPARISION

BETWEEN LIME NEUTRALIZATION AND DEEP WELL METHODS OF WASTE DISPOSAL

	Dollars Per Month	
	Neutralization	Deep Well
Labor (Incl. Benefits)	$ 3,214.	$ 875.
Repair and Maintenance	10,807.	2,312.
Electricity	576.	200.
Steam Utilities	4,014.	0.
Water	64.	400.
*Lime	9,295.	0.
Supplies	910.	197.
Services	832.	291.
Tech. and Administrative	3,260.	907.
TOTAL	$ 32,972.	$ 5,182.

*Cost of lime delivered has increased 29.9% since the above lime cost was calculated.

Exhibit 4 - Cross Section of Planned Central Design

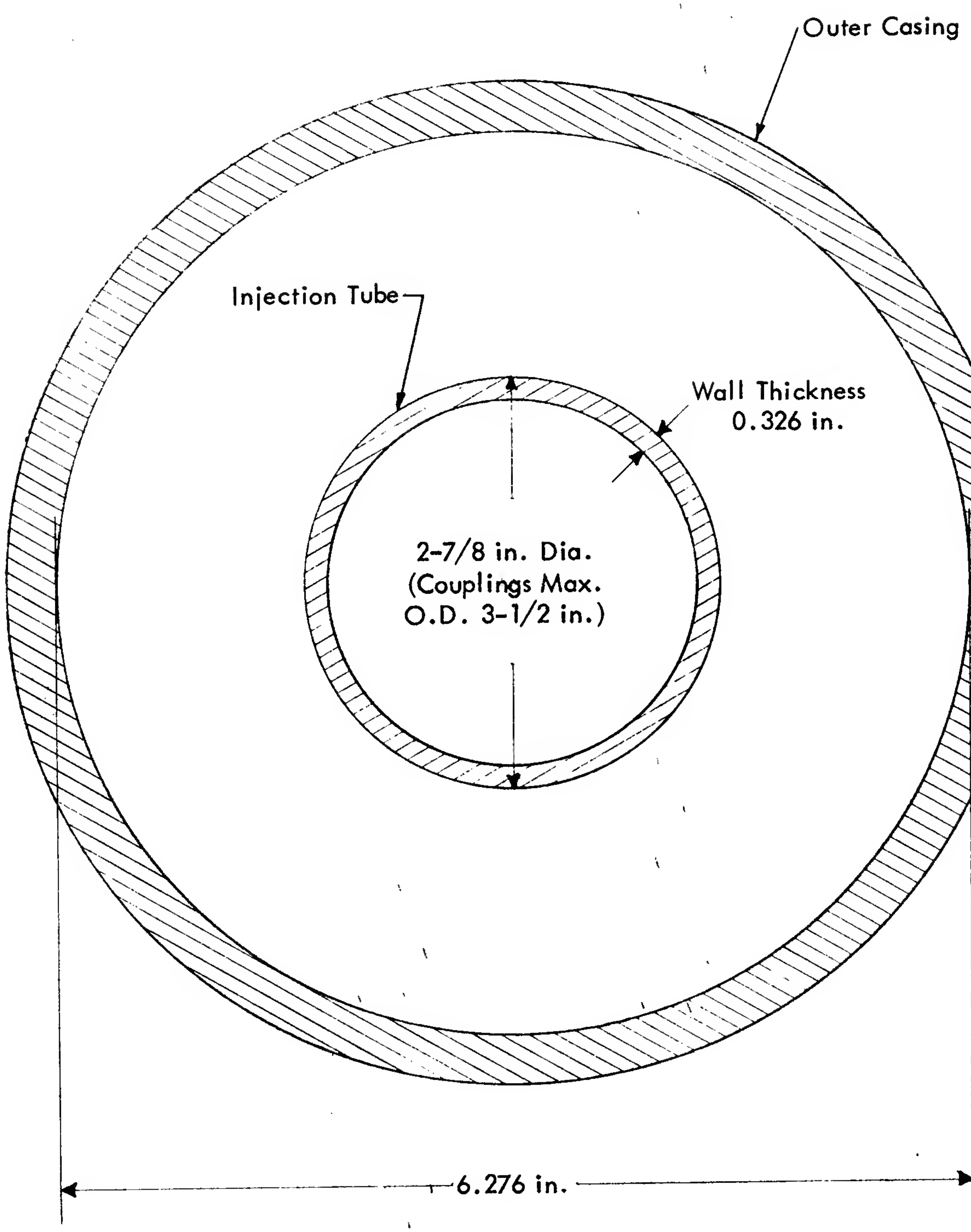


Exhibit 5. Fibercast Pipe

February 23, 1967

SPECIFICATIONS FOR 2-7/8" O.D. TUBING

	Operating	Ultimate
1. Internal Pressure		
150° and 200° F.	575	2,000
300° F.	250	1,500
2. Collapse		
150° F.	500	2,500
200° F.	375	1,875
300° F.	250	1,250
3. Tensile (thread shear controlling)		
150° and 200° F.	7,500	40,000
300° F.	4,000	30,000

4. Coupling Dimensions

   Same as Catalog - Figure 1 x 2-1/2"

Exhibit 6 - Consultant's Estimates of Pressures Required for Operation

A. Feet of Pressure Required to Force Annulus Water (at 1 gallon/min.) and Waste Pickle Liquor (Specific Gravity of 1.2) into the Sandstone Layer at Various Flowrates.

Acid Flowrate (gal./min.)	Feet of Pressure Head Required (Ft.) Water	Waste Pickle Liquor
0	2410	2010
50	2475	2060
100	2545	2120
150	2615	2180
200	2680	2230
250	2750	2290
300	2820	2350

B. Feet of Pressure Required to Force Waste Pickle Liquor (Specific Gravity of 1.2) Through 2,500 feet of Tubing of Various Sizes Against Wall Friction of the Tubing.

Acid Flowrate (gal./min.)	Injection Tubing O.D. (in.)			
	2-3/8	2-7/8	3-1/2	4-1/2
	Required Pressure Head (ft.)			
50	188	50	18	5
100	650	175	63	19
150	1375	350	127	40
200	2380	625	225	68
250	3500	900	325	100
300	5000	1250	450	140